Solitary High-Q Resonance in a Grating Waveguide via Parity Symmetry Breaking at a Mode Crossing

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A phenomenon of a solitary narrow high-Q resonance in a planar grating waveguide (Fig. 1a) is revealed. It occurs at a certain point of degeneracy in the parameter space and at a frequency where dispersion curves of two infinite-grating eigenmodes of opposite spatial parities intersect each other. At this point, the leaking infinite-grating eigenmode breaks its parity symmetry and becomes decoupled from a spatial Fourier harmonic leaking outside the grating waveguide. As a result, the low-Q waveguide eigenmode associated with those two infinite-grating eigenmodes acquires a very high Q-factor in a narrow vicinity of the mode-crossing point (Fig. 1b). The predicted phenomenon of a solitary high-Q resonance, which takes place due to coupling between two partial modes resulting in decoupling of the waveguide eigenmode from a radiation-loss channel, is of general nature and could exist in various photonic structures and crystals.

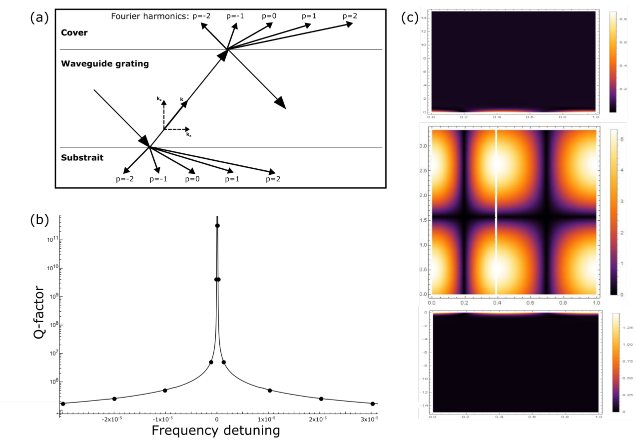

Figure 1: Solitary high-Q mode in a grating waveguide: (a) Geometry of the wave propagation in the planar grating waveguide and wave scattering at the borders with the cover and substrate; (b) Q-factor as a function of the eigen-frequency detuning from the frequency of degeneracy; (c) Distribution of the electric field amplitude, localized inside the grating layer and evanescent outside the borders with the cover and substrate layers

In this talk we focus on the planar-grating waveguide eigenmode with zero longitudinal wavenumber, $k_x = 0$, when just one central, zeroth spatial Fourier harmonic is escaping outside the waveguide and into the cover or/and substrate medium, while all other Fourier harmonics are evanescent and, hence, do not contribute to the radiative losses (Fig. 1c). The infinite-grating eigenmode, whose longitudinal profile is odd on each uniform segment of the grating relative to the center of this segment, has a very small contribution from the zeroth Fourier harmonic and practically no radiative losses. At the same time, the infinite-grating eigenmode, whose longitudinal profile is even on each uniform segment of the grating relative to the center of this segment, has a dominant contribution from the zeroth Fourier harmonic and large radiative losses.

The solitary high-Q resonance originates from a parity symmetry breaking at the mode-crossing point where the eigenmodes of almost pure opposite parities acquire a mixed odd-even profiles due to a critical mutual coupling. Such a phenomenon exists only in a few very narrow regions of the multi-dimensional space of the grating waveguide parameters. A guidance from the explicit formulae of the analytic theory of the grating eigenmodes [1] is crucial for identifying and finding those narrow islands of parameters required for designing photonic structures supporting such high-Q resonances. We explain this phenomenon using a waveguide based on the titanium oxide (TiO_2) – optical material known for many applications in photonics. The solitary narrow high-Q resonances could find a number of various applications.

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References

[1] V V Kocharovsky, C B Reynolds and Vl V Kocharovsky, Phys. Rev. A **100**, 053854 (2019)